CHAPTER 2

SYSTEM CONSIDERATIONS

2.1 INTRODUCTION

A nuclear air cleaning system is an assembly of interrelated, interactive parts that include the air cleaning system components, the contained space served by the air cleaning system (e.g., the glovebox, hot cell, room, or building), and the processes served by that system.

This chapter discusses the design, operational, regulatory, and codes- and standards-related requirements for nuclear facility air cleaning systems. Topics will include system, subsystem, and component design considerations, as well as general descriptions of various systems used in nuclear power plants, fuel processing and reprocessing plants, research facilities, storage facilities, hot cells, gloveboxes, and other applications. This chapter will also consider operating costs and how the design of an air cleaning system directly affects the ventilation system performance and costs. In addition, examples of some of the special considerations (i.e., "lessons learned") from the design, construction, modification, and operation of nuclear air cleaning systems will be provided.

2.2 ENVIRONMENTAL CONSIDERATIONS

The complexity of the air cleaning system needed to provide satisfactory working conditions for personnel and to prevent the release of radioactive or toxic substances to the atmosphere depends on the following factors.

- Nature of the contaminants to be removed (e.g., radioactivity, toxicity, corrosivity, particle size and size distribution, particle shape, and viscidity)
- Heat
- Moisture
- Other environmental conditions to be controlled
- Probability of an upset or accident
- Extent of hazard in the event of an upset or accident

Environmental parameters are the most important and often understated data required to develop a satisfactory air cleaning system. In designing an air cleaning system, development of the environmental operating conditions must be the first step. Although many individual system components may be environmentally qualified, the designer must consider all environmental parameters on a "system basis." This may require additional qualification to validate components.

The facility owner or architectural engineering firm normally identifies the design and environmental parameters that are compatible with the overall facility design. These parameters must be identified prior to system design because they must be the basis for the equipment design. If the environmental parameters are carefully considered, a detailed analysis of cost versus long-term operation will provide an environmental maintenance schedule for replacing components and parts throughout the intended operational life of the system. This will ensure that the system will perform its intended function properly, efficiently, and cost-effectively.

TABLE 2.1 lists the most common system environmental parameters to be considered for system design.

Table 2.1 – Environmental Parameters for System Design

Type of Gas(es)	Air, hydrogen, oxygen.
Flow rate(s)	The maximum and minimum operating flow rate at normal and accident conditions.
Pressure	The external pressure and/or vacuum level at the inlet and outlet of the system; the maximum system pressure, usually accident or upset mode; and/or the maximum allowable pressure drop across the air cleaning system.
Temperature	The maximum and minimum operating temperatures of the air stream and equipment.
Radiation Levels	Alpha, beta, and gamma radiation, both maximum and cumulative dose levels (rads).
Relative Humidity	The maximum and minimum relative humidity of the gas entering the air cleaning system.
Projected Levels of Contaminants to be removed from the gas stream	Particulate, gaseous, entrained water, chemical, radiological, other.
Presence of other contaminants	Particulate, gaseous, chemical, volatile organic chemicals (VOCs), hydrofluoric acid/hydrogen fluoride and progenitor compounds, nitric acid, others.
Seismic Requirements	Facility seismic response curves or g-loads.
Pressure-Time Transients	Pressure-time transients that the air cleaning system may experience.
Other Upset Conditions	See Section 2.3.1.1.
Design Life	Projected facility operating life.

2.2.1 AIRBORNE PARTICULATES AND GASES

To properly design an air cleaning system and optimize its performance, the types of contaminants in the gas stream must be identified. All of the contaminants, both particulate and gaseous, including concentration levels and particle sizes, must be evaluated to properly design and size the system. The presence of other particulates, gases, and chemicals must be clearly determined. The presence of volatile organic chemicals (VOCs), entrained water droplets, and acids will affect the performance of various system components and must be addressed, if they are present, in the design of the system and its components.

Intake air cleaning systems or supply systems filter the atmospheric dust brought into the facility. Recirculating systems, if used, clean the air in a building or location and return the air to that location. Other sources of particulate and gaseous contamination are infiltration and "people-generated" particulates (e.g., lint, skin, hair) and off-gassing of materials such as paint, solvents, carpets, and furniture. All of these factors must be considered in determining the parameters for proper system design. These contaminants contribute to degradation and sometimes become radioactive when exposed to certain environments (e.g., by adsorption of radioactive vapors or gases or by agglomeration with already radioactive particles). Because particles in the size range of 0.05 to 5 μm tend to be retained by the lungs when inhaled, they are of primary concern in operations that involve radioactive material.[7] They are also recognized as among the health hazards of nonradioactive air pollution.[8] As shown in **TABLE 2.2**, over 99 percent, by count, of typical urban air samples have a mean particle size of 0.05 μm.

Reports of dust concentrations in air are generally based on the masses of the particulate matter present. As shown in TABLE 2.2, mass accounts for only a negligible portion of the total number of particles in the air. This is important in filter selection because it indicates that some filters with

Table 2.2 – Distribution of Particles in Typical Urban Air Sample

Mean particle site (μm)	Particle size range (μm)	Approximate particles count per cubic foot of air	Percent by weight	Percent by count
20.0	50 - 10	12.5×10^{3}	28	1×10^{-10}
7.5	10 - 5	10×10^{4}	63	8×10^{-10}
2.5	5 - 1	12.5×10^{6}	6	1×10^{-7}
0.75	1 - 0.5	10×10^{7}	2	8×10^{-7}
0.25	0.5 - 0.1	12.5×10^{9}	1	1×10^{-4}
0.05	0.1 - 0.001	12.5×10^{15}	<1	99.9999

Source: The Frank Chart, American Air Filter Co., Louisville, KY.

a high efficiency based on weight may be inefficient on a true count basis. That is, the filters are efficient for large particles, but inefficient for small (less than 0.75-μm) particles. This is true of most common air filters used as prefilters. On the other hand, the high-efficiency particulate air (HEPA) filter is highly efficient for all particle sizes down to and including the smallest shown in TABLE 2.2. The 99.97 percent minimum efficiency claimed for these filters is actually for the most penetrating size particles, i.e., those ranging in size from 0.07 to 0.3 μm. Dust concentrations vary widely from place to place and, for the same location, from season to season and from time to time during the same day. Concentrations in the atmosphere may vary from as low as 0.01 grain per 1,000 ft^3 in rural areas to more than 10 grains per 1,000 ft^3 in heavily industrialized areas. Dust-producing operations may generate concentrations as great as several thousand grains per 1000 ft^3 at the workplace. Because the weight percent determinations on which these concentrations are based account for only a small fraction of the number of particles present, the true count of particles smaller than 5 μm may number in the billions per 1000 ft^3. Atmospheric dust concentrations are usually lowest during the summer months (June 1 to August 1)—as much as 30 percent lower than during the remainder of the year.[9]

Filter selection, particularly prefilter and building supply filter selection, must consider the atmospheric dust concentrations that can be encountered at a particular site at any time of the year.

FIGURE 2.1 shows the distribution of particles (by weight percent) in atmospheric air as a function of particle shape. Variations in particle shape, mean particle size, particle size range, and concentration affect filter life, maintenance costs, and operational effectiveness. The size range of various types of particles, the technical nomenclature of various types of aerosols, and the applicability of various types of air cleaning devices as a function of particle size are shown in **FIGURE 2.2.** A major source of the lint often found on filters is derived from the abrasion of clothing as people move about. In addition, a person at rest gives off more than 2.5 million particles (skin, hair, etc.) and moisture droplets/min in the size range of 0.3 to 1 μm.[10] Process-generated aerosols fall into two general size ranges. Those produced by machining, grinding, polishing, and other mechanical operations are generally large, (from 1 to several hundred μm), according to the nature of the process, and can be removed effectively by

Description	Appearance	Kinds	Percent Present by Weight	
			Range	Average
Spherical		Smokes Pollens Fly ash	0-20	10
Irregular cubic		Minerals Cinder	10-90	40
Flakes		Minerals Epedermis	0-10	5
Fibrous		Lint Plant fibers	3-35	10
Condensation flocs		Carbon Smokes Fumes	0-40	15

Figure 2.1 – Distribution of particles

common air filters or other conventional air cleaning techniques. The other size range includes those produced by evaporation/condensation and other chemical operations, which generate droplets and solid particles that are often submicrometer-sized. These aerosols are more difficult to separate from air or gases, requiring collectors such as HEPA filters. Ultra Low Penetration Air (ULPA) filters provide a higher cleaning efficiency (up to 99.9999 percent for submicrometer particles). A need for this level of efficiency is rare for nuclear applications. In addition, the media used in ULPA filters is weaker than that used in nuclear-grade HEPA filters, a factor that must be considered for any application of ULPA filters to a nuclear air cleaning system or other applications where durability and reliability are concerns.

Other process-generated contaminants include radioactive halogen and noble gases. Because of their chemical inertness, limited reactivity with available sorbents, and the great difficulty of separating them, the noble gases (xenon and krypton) have been treated in the past by simple holdup to allow time for radioactive decay of the shorter half-life elements, as well as dilution before discharge to the atmosphere. The preferred method is to separate the noble gases by cryogenic fractionation, charcoal adsorption, or fluorocarbon absorption, and to store them until a significant degree of radioactive decay can take place. The halogen gases, essentially elemental iodine and certain organic iodides, constitute the largest fraction of the gaseous effluents and are captured by adsorption on activated carbon or certain synthetic zeolites. Hydrogen fluoride is at least a theoretical concern because it will attack the glass media. Wood-case filters may also be vulnerable to attack by nitric acid that will form nitrocellulose.

2.2.2 PRESSURE

Pressure is one of a number of variables that needs to be evaluated in the course of designing the air cleaning system because it can significantly affect the fan power requirements and the air flow rate. The pressure of the air stream can be impacted significantly by the change from the normal operating pressure to the accident or upset air pressure that can be essentially a steam/air mixture. This change can be abrupt, with a slowly decreasing rate as the moisture is condensed and removed from the air stream.

2.2.3 MOISTURE

Moisture is an important consideration in air cleaning system design. Moisture in the air affects the performance of the air cleaning system by binding the particulate filters and blocking pores and fissures in the activated charcoal, thereby reducing the active sites available for adsorption. Where heavy concentrations of water mist or steam can be expected under either normal or upset conditions, heaters, moisture separators, or other means of reducing entrained moisture to tolerable levels must be provided upstream of the filters to prevent plugging, deterioration, and reduced performance. Condensation from saturated air or gas streams and carry-over from air washers and scrubbers are common sources of moisture. When fire-protection sprinklers are provided in operating areas or ducts, moisture can be drawn into the filters if they are activated in the event of a fire. In nuclear reactors, large volumes of steam and moisture would be expected in the very unlikely event of a major loss-of-coolant accident (LOCA) or heat exchanger failure. Moisture on the face of a filter will blind or plug the filter, creating the potential for filter failure.

Condensation is particularly troublesome when filters are installed in underground pits, in outdoor housings, or in unheated spaces within buildings. Even when the air entering through the ducts is above the dew point, duct walls, dampers, or filters may be cold enough to cause condensation on their surfaces. Condensation can also take place in standby systems, particularly when groundwater can evaporate into the filter housing to condense on walls, mounting frames, or filters. In addition, salts that leach from wood filter casings can rapidly deteriorate aluminum separators. For this reason, periodic ventilation of standby filters on a monthly or even weekly basis is recommended to prevent such occurrences.

An excellent reference to assist in the evaluation of moisture effects is *Thermal Environmental Engineering, Second Edition,* by James L. Threlkeld, (Prentice-Hall, Inc., 1970). [12]

2.2.4 TEMPERATURE

Although some air cleaning system components are prequalified to operate in a given temperature range, the air cleaning system designer must verify all components of the system will function at the maximum and minimum temperature conditions for the specified application. If the temperature range of the specific application exceeds the components' design qualification temperature, requalification is necessary to meet the operational and design life requirements of the system.

Continuous operation at high temperature (greater than 200 degrees Fahrenheit (93 degrees Celsius) is detrimental to both HEPA filters and activated carbon-filled adsorbers. At high temperatures, the shear strength of adhesives and binders used in the manufacture of prefilters, HEPA filters, and filter media may diminish, thereby limiting the safe pressure drop to which they can be subjected. The limiting temperature varies with the specific adhesive and binders used. The filter manufacturer should provide objective evidence that the filters are qualified for the temperature environment of the specific application as part of the environmental qualification.

For high-temperature applications, particulate filtration can be accomplished with the use of metal filters constructed of sintered metal or metal mesh. The construction and performance requirements for metal filters can be found in American Society of Mechanical Engineers (ASME) Code AG-1, "Code on Nuclear Air and [30] Metal filters are manufactured for medium efficiency and HEPA efficiency ranges. Due to their relatively high cost, metal filters should be considered for those applications where standard glass fiber filters would not meet the environmental or design conditions.

The limiting temperature of adsorbents for capturing radioactive iodine and iodine compounds is related to the desorption temperature of the adsorbed compound and the impregnants with which the material has been treated to enhance its adsorption of organic radioiodides. For triethylene-diamine- and iodine-impregnated activated carbon, this temperature may be as low as 280 degrees Fahrenheit (134 degrees Celsius).

When temperatures higher than the operating limits of air cleaning system components must be accommodated, chilled water coils, heat sinks, dilution with cooler air, or some other means of cooling must be provided to reduce temperatures to levels that the components can tolerate. Environmental qualification of an air cleaning system must address thermal expansion and the heat resistance of ducts, dampers, filter housings, component mounting frames and clamping devices, and fans. Electrical and electronic components are specifically susceptible to high and low temperatures and must be designed and qualified in accordance with the ASME AG-1 Code[32] and Institute of Electrical and Electronics Engineers (IEEE) 323, "Standard for Qualifying Class 1E Equipment for Nuclear Generating Stations"[40] and IEEE 344, "Recommended Practice for Seismically Qualification of Class 1E Equipment for Nuclear Power Generating Stations."[40] Operational consideration also must be given to the flammability of dust collected in the ducts and on the filters.

2.2.5 CORROSION

Many radiochemical operations generate acid or caustic fumes that can damage or destroy filters, system components, and construction materials. The air cleaning system designer must select components and materials of construction suitable for the caustic environment to ensure high levels of system performance and reliability.

Acid-resistant prefilters and HEPA filters are available. These filters utilize media constructed with Nomex or Kevlar fibers mixed with glass fibers during manufacturing; epoxy-coated separators to extend the life of the aluminum separators; and stainless steel frames.

Metal filters with a demonstrated suitability for a corrosive atmosphere, in accordance with the ASME AG-1 Code[30], are recommended for hydrogen fluoride or other highly acidic applications.

Stainless steel is recommended for ductwork and housings when corrosion can be expected. Even this material may be insufficient in some cases, and coated (e.g., vinyl, epoxy) stainless steel or fiber-reinforced plastics may be necessary (corrosion-resistant coatings are covered by ANSI N512.[13] The system designer can either (1) use existing databases containing information about the performance of materials exposed to various concentrations of corrosive contaminants or (2) perform actual testing to validate the air cleaning system design.

Scrubbers or air washers may be employed to pretreat the air or gas before it enters the air cleaning system, but consideration must also be given to moisture carry-over if the scrubbers or air washers are not designed and operated properly. Stainless steel moisture separators are recommended ahead of the filters. Corrosion is always a danger, but is not always obvious. In activated carbon-filled adsorbers, for example, even trace amounts of nitrous oxide or sulfur dioxide will concentrate in the adsorbent over time. In the presence of moisture, these compounds can form nitric or sulfuric acids that are capable of corroding the stainless steel parts of the adsorber, i.e., the perforated metal screens. Aluminum and carbon steel are subject to corrosion when in contact with moisture-laden carbon. For this reason, stainless steel is always specified for adsorber cells and for adsorber-cell mounting frames.

Electrical and electronic components are particularly susceptible to corrosive atmospheres. Plastics become brittle over time, contacts corrode, etc. For this reason, all electronic components must be environmentally qualified for the intended application.

Care must be exercised in selecting and using gaskets, as some gasket material reacts with the moisture in the air stream and releases chlorides that can corrode steels (including stainless steel). Gasket material selection should also include consideration of the effects of the material's use in acidic or other harsh environments.

2.2.6 VIBRATION

Vibration and pulsation can be produced in an air or gas cleaning installation by turbulence generated in poorly designed ducts, transitions, dampers, and fan inlets and by improperly installed or balanced fans and motors. Excessive vibration or pulsation can result in eventual mechanical damage to system components when vibrational forces become high or when accelerative forces (e.g., from an earthquake or tornado) coincide with the resonant frequencies of those components. Weld cracks in ducts, housings, and component mounting frames may be produced by even low-level local vibration if sustained, and vibrations or pulsations that produce no apparent short-term effects may cause serious damage over longer periods.

Vibration produces noise that can range from the unpleasant to the intolerable. Important factors in the prevention of excessive vibration and noise include planning at the initial building layout stage and space allocation to ensure that adequate space is provided for good aerodynamic design of ductwork and fan connections. Spatial conflicts with the process and with piping, electrical, and architectural requirements should be resolved during early design to avoid the compromises so often made during construction that frequently lead to poor duct layout and resulting noise and vibration. Ducts should be sized to avoid excessive velocities while maintaining the transport velocities necessary to prevent the settling out of particulate matter during operation. Fan vibration can be minimized through the use of vibration isolators and inertial mountings. Some designers require hard mounting of fans where seismic requirements and continued operation during and after an earthquake must be considered. Flexible connections between the fan and ductwork are often employed, but these must be designed to resist seismic loads and the high static pressures, particularly in those parts of the system that are under negative pressure. Finally, the ductwork system must be balanced after installation, not only to ensure the desired airflows and resistances, but also to "tune out" any objectionable noise or vibration that may have been inadvertently introduced during construction.

2.2.7 ELECTRICAL

Emergency electrical power from the facility's power system is required for all safety air cleaning systems. The amount of emergency power required for fans, dampers, valves, controls, and electrical heaters to control the relative humidity of the effluent air stream (as dictated by the facility design requirements) must be accounted for during accident or upset conditions. Close coordination between the system designers of both the air cleaning and electrical systems is required to ensure this is done, as there is a set amount of emergency power available.

2.2.8 RADIATION

Radiation is the propagation of energy through matter or space in the form of electromagnetic waves or fast-moving particles (alpha and beta particles, neutrons, etc.). Gamma rays are electromagnetic radiation in which the energy is propagated in "packets" called photons.

Radiation poses material degradation and personnel exposure problems. Material degradation must be addressed during the design and operation of the facilities. Personnel exposure must be continuously measured and monitored. Radiation dose rates are provided in 10 CFR 50, Appendix I.[3]

2.2.9 ZONING

Workroom ventilation rates are based primarily on cooling requirements, the potential combustion hazard, and the potential inhalation hazard of substances that are present in or could be released to the workroom. Concentrations of radioactive gases and aerosols in the air of occupied and occasionally occupied areas should not exceed the concentration guides (CG) established for occupationally exposed persons under normal or abnormal operating conditions, and releases to the atmosphere must not exceed permissible limits for non-occupationally-exposed persons.[1,2] Because radioactive gases and aerosols might be released accidentally in the event of an equipment failure, a spill, or a system upset, the ventilation and air cleaning facilities must be designed to maintain airborne radioactive material within prescribed limits, even following the worst conceivable accident that could occur in the plant.[2] Control is made more difficult by the "as low as reasonably achievable" (ALARA) requirements which, at least for light water reactors, restrict gaseous and airborne particulate effluents to levels such that continuous exposure of persons in unrestricted spaces of the plant and its environs will not exceed the design objective annual dose limits set forth in 10 CFR 50, Appendix I.[3]

The current CGs for radioactive substances in air are specified in 10 CFR 20.[1] A building or facility can be divided into confinement zones with respect to the hazard classes shown in **TABLE 2.3** and based on the criteria shown in **TABLE 2.4**. The limits given in TABLE 2.4 are guides and should not be considered absolute. By introducing such indexes of potential hazards and limitations on the quantities of materials that can be handled, it is possible to establish a basis for ventilation and air cleaning requirements in various parts of a building or plant. **FIGURE 2.3** illustrates a typical zoning plan for a nuclear facility showing permitted occupancies, pressure differentials between zones required for proper ventilation and contaminant control, and zone assignments. Not all of the confinement zones listed in TABLE 2.4 would be required in all buildings, and an entire building could possibly be designated a single zone. Confinement zones are defined with respect to function and permitted occupancy in the following paragraphs.

Primary Confinement.[35] Areas include the interior of a hot cell, glovebox, piping, vessels,

Table 2.3 – Hazard Classification of Radioisotopes

Hazard Class	Hazard	CG, air (Ci/liter)	Amount of radioactive materials permitted[a] (μCi)
1	Very high	$<10^{-13}$	0.1
2	High	10^{-13} to 10^{-11}	1.0
3	Moderate	10^{-11} to 10^{-9}	10.0
4	Negligible	$<10^{-9}$	100.0

[a] Amount of radioactive material that can be handled without special protection for personnel.

tanks, glovebox exhaust ductwork, primary confinement HEPA filter plenums, or other containment for handling highly radioactive material. Containment features must prevent the spread of radioactive material within as well as release from the building under both normal operating and upset conditions up to and including the design basis accident (DBA) for the facility. Complete isolation (physical separation) from neighboring facilities, laboratories, shop areas, and operating areas is necessary. Entry must be forbidden until the area is cleaned up to Secondary Confinement classification. An air exhaust system that is independent of those serving surrounding areas is required. High-efficiency filters, preferably HEPA type, are required in air inlets, and two independently testable stages of HEPA filters are required in the exhaust. Entry is permissible only with full-body protective clothing and respirators or full-face gas masks, as specified by a health physicist.

Secondary Confinement.[35] This zone area consists of the walls, floors, roof and associated ventilation systems that confine any potential release of hazardous materials to primary confinement. Areas include glovebox operating areas, hot cell service or maintenance areas, or other building spaces where high levels of radiation could be present. Particularly hazardous operations must be conducted in chemical fume hoods or gloveboxes. Sufficient air supply to produce inward airflow into the fume hoods or glovebox ports (with the glove removed) of at least 100 linear fpm, and maybe 200 fpm for particularly hazardous operations or if hot plates, burners, or aspirators are operated within such containment. Air locks or a personnel clothing-change facility are recommended at the entrance to the zone. Continuous monitoring of airborne radioactive material is required. Personnel should at least wear laboratory coats and possibly shoe covers in glovebox operating areas, and full protective clothing in service areas. Respirators or full-face gas masks should be available in the event of an operational upset. Restricted access areas are generally included in the Secondary Confinement Zone hazard classification.

Tertiary Confinement.[35] This zone area consists of the walls, floors, roofs, and associated exhaust system of the process facility. It is the final barrier against release of hazardous material to the environment. This level of confinement is never expected to become contaminated.

Multizoned buildings are usually ventilated so that air flows from the less contaminated zone to the more contaminated zone. Recirculation within a zone (circulating the air through a high-efficiency air cleaning system before discharge back to the zone) might be permitted, but recirculation from a zone of higher contamination back to a zone of lesser contamination is prohibited. The insides of exhaust and recirculating ductwork are considered

Table 2.4 – Zoning of Facilities Based on Radiotoxicity of Materials Handled

Radiotoxicity of isotopes	Quantity of Material Handled versus Radiotoxicity			
	Primary Confinement	Secondary Confinement	Secondary Confinement	Tertiary Confinement
Very high[a]	>10 mCi	10 μCi -10 mCi	0.1 μCi -10 μCi	0 - 0.1 μCi
High	>100 mCi	100 μCi - 100 mCi	1.0 μCi - 100 μCi	0 - 1.0 μCi
Moderate	>1 Ci	1 mCi - 1 Ci	10 μCi - 1 mCi	0 - 10 μCi
Slight	>10 Ci	10 mCi - 10 Ci	100 μCi - 10 mCi	0 - 100 μCi

[a] There is an upper limit to the quantity of transuranium elements that should be approved for glovebox operations. As a general rule, for those isotopes with a gram HEP index number below 10^{-4}, the limiting quantity should be 100 mg (for example, 100 mg of Cm-244 generates the same hazard equivalent potential of 4.3 kg of Pu-239). Any operation involving more than 100 mg of such isotopes should be conducted at facilities with more absolute containment features than are offered by gloveboxes alone. This number may require further reduction due to penetrating radiation. One g of Cf-252, for example, generates a dose rate of 2400 rems/hr at a distance of 1 m in air.

Source: Procedures and Practices for Radiation Protection, Health Physics Manual, Oak Ridge National Laboratory, Oak Ridge, TN.

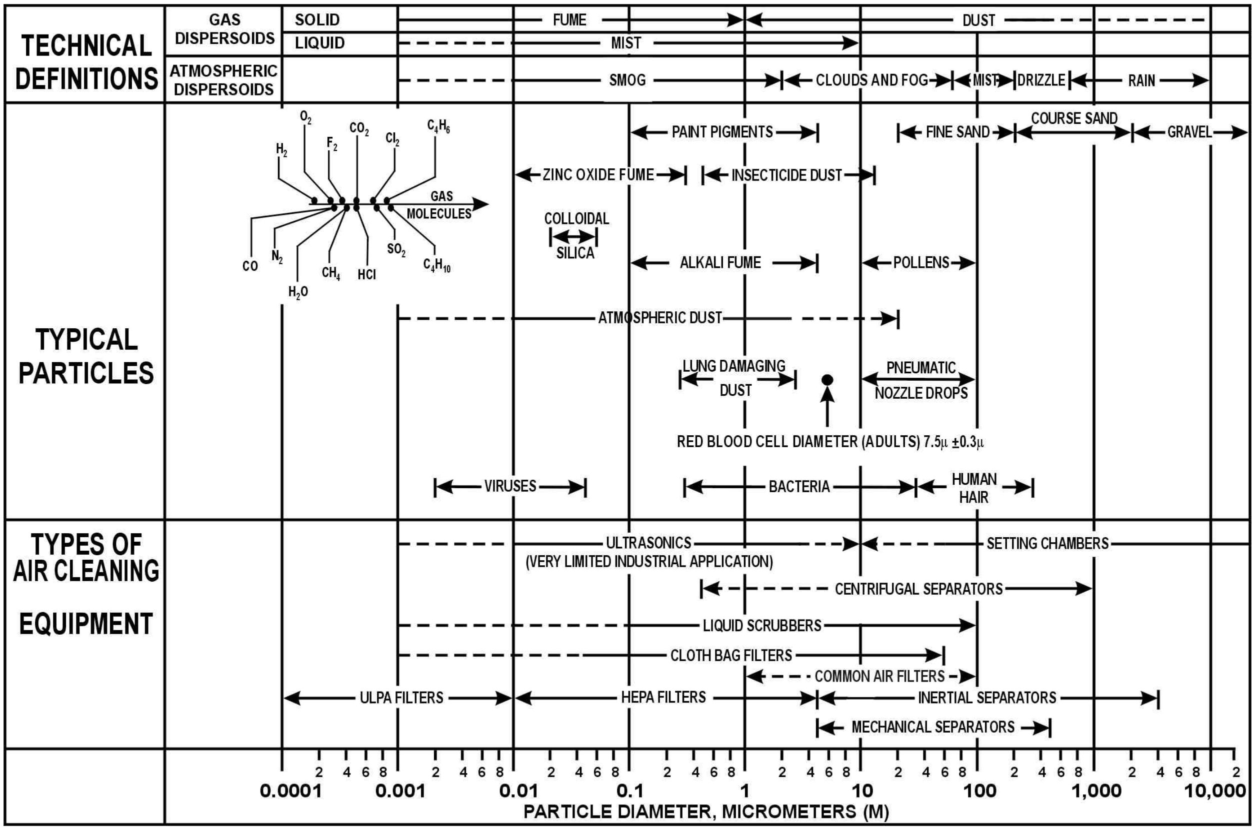

Figure 2.2 – Characteristics of atmospheric and process-generated particulates, fumes, and mists and effective range of air cleaning equipment

to be of the same hazard classification as the zone they serve. Airflow must be sufficient to provide the necessary degree of contaminant dilution and cooling and to maintain sufficient pressure differentials between zones where there can be no backflow of air spaces of lower contamination, even under upset conditions. A pressure differential (Δp) of at least 0.1 in.wg between building zones is recommended, and substantially higher differentials (0.3 to 1.0 in.wg) are often specified between Secondary and Primary Confinement Zones. The criteria listed in **TABLES 2.5, 2.6, 2.7, 2.8, and 2.9** are specified at one of the U.S. Department of Energy (DOE) national laboratories for the design and operation of radiochemical and laboratory facilities and for the buildings that contain them.[4] [Note that numerical values can be relaxed or increased depending on the requirements for operating conditions and the DBA for that facility.]

Concentration limits for radioactive substances in air are specified in 10 CFR 20.[1] The TLVs of toxic and noxious substances, including irritant and nuisance substances, are specified in 10 CFR 29 (Labor), but are more conveniently tabulated by the American Conference of Governmental Industrial Hygienists in the annual issue of TLVs.[4] The latter reference includes a procedure for determining TLVs for mixed toxicants, as well as limit values for heat stress, nonionizing radiation, and noise.

Table 2.5 – Airflow Criteria for Design and Operation of Hot Cells, Caves, and Canyons (Primary Confinement)

1. A vacuum equal to or greater than 1 in.wg relative to surrounding spaces must be maintained at all times to ensure a positive flow of air into the containment.
2. Containment exhaust must be at least 10 percent of cell volume/min to minimize possible explosion hazards due to the presence of volatile solvents and to ensure that, in the event of cell pressurization due to an explosion, the containment will be returned to normal operating pressure (1 in.wg) in a minimum of time.
3. The maximum permissible leak rate must be 1 percent of cell volume/min for unlined cells and 0.1 percent of cell volume/min for lined and sealed cells at a Δp of 2 in.wg to ensure minimal escape of radioactive material in the event of cell pressurization; the maximum permissible leak rate for ductwork is 0.1 percent of duct volume/min at Δp equal to 1.5 times the static pressure of ductwork.
4. Seals and doors must withstand a Δp of at least 10 in.wg to ensure the integrity of closures and penetrations under all operating and design basis upset conditions.
5. The containment structure must withstand the DBA for that facility without structural damage or loss of function.
6. Operating procedures must be designed to limit quantities of flammable and smoke-producing materials and solvents within limits that can be accommodated by the ventilation system without endangering the function ability of the air cleaning facility.

Table 2.6 – Airflow Criteria for Gloveboxes (Primary Confinement)

1. Gloveboxes (air) typically operate at –0.7 to –1.0 in.wg. Gloveboxes (inert gas) typically operate at –0.7 in.wg.[35] The vacuum must be at least 0.3 in.wg between the glovebox and the surrounding room. Consult the latest edition of the American Glovebox Society's *Guidelines for Gloveboxes*, AGS-G001,[57] and the American Conference of Governmental Industrial Hygienists' *Industrial Ventilation – a Manual of Recommended Practice*[36] for guidance concerning ventilating gloveboxes.
2. The exhaust rate is not specified, but must be adequate for the heat load and dilution requirements of operations conducted in the glovebox. For example, operations with flammable materials must maintain concentrations below the specified concentrations.
3. Airflow must be sufficient to provide an adequate face velocity at the pass-through port to the glovebox (50 linear fpm) and to maintain an inward velocity of at least 125 linear fpm (with higher velocities mandated by some operators for gaseous effluents) through one open glove port in every five gloveboxes in the system. This will ensure adequate inflow to prevent the escape of contamination in the event of glove failure.
4. Individual gloveboxes must be isolated or isolatable (under upset conditions) to prevent fire spreading from one box to another.

Table 2.7 – Airflow Criteria for Chemical Fume Hood (Primary Confinement)

5. A vacuum must be at least 0.1 in.wg between the laboratory in which the fume hood is installed and the corridor from which the laboratory is entered.
6. The exhaust rate of the fume hood must be sufficient to maintain sufficient airflow face velocity into the hood to prevent the release of fumes from the hood to the room, even when the operator walks rapidly back and forth in front of and close to the hood face. A face velocity of 80 to 100 linear fpm is recommended for operations with highly hazardous (including radioactive) materials. Higher velocities were once recommended, but are not now due to the generation of vortices by faster airflows which cause air inside the hood to migrate to the outside. Consult the latest edition of the American Industrial Hygiene Association's *American National Standard for Laboratory Ventilation*, Z9.5,[55] for guidance.
7. Each hood in the laboratory should be isolatable by means of dampers to prevent backflow through a hood when it is not in service.
8. Each hood used for handling radioactive materials should have a HEPA filter in its exhaust duct, located close to the duct entrance. All hoods should, where practicable, exhaust to a common stack or a cluster of stacks.

Table 2.8 – Airflow Criteria for Secondary Confinement Structures or Buildings

1. The building (structure) must be designed to prevent the dispersal of airborne contamination to the environment in the event of an accident in a hot cell, glovebox, fume hood, or building space.
2. Under emergency conditions, the building must be capable of being maintained at a vacuum of 0.2 to 0.3 in.wg relative to the atmosphere. For increased reliability and simplicity, some buildings are held at this pressure under normal operating conditions. However, if this is not practicable, the ventilation system must be capable of reducing building static pressure to 0.2 in.wg in 20 sec or less. All building air must be exhausted through at least one stage of HEPA filters. During an emergency, the differential between primary confinement spaces (gloveboxes, hot cells) and other building spaces must also be maintained.
3. Airflow within the building must be from areas of less contamination to areas of higher (or potentially higher) contamination.
4. Recirculation of air within the same zone or room is permitted, but recirculation from the central exhaust system is prohibited.

Table 2.9 – Airflow Criteria for Air Handling Systems

1. It is recommended that ventilation (recirculating, supply, or exhaust) and off-gas systems must be backed up by redundant air cleaning systems (including filters and fans) to maintain containment in the event of fan breakdown, filter failure, power outage, or other operational upset. Airflow must always be from the less hazardous to the more hazardous area under both normal and upset conditions.2.Air exhausted from occupied or occasionally occupied areas must be passed through prefilters and at least one stage of HEPA filters. Contaminated and potentially contaminated air exhausted from a hot cell, cave, canyon, glovebox, or other primary confinement structure or vessel must pass through at least two individually testable stages of HEPA filters in series, as well as prefilters, adsorbers, scrubbers, or other air cleaning components that are required for the particular application. Only one stage of HEPA filters is required for the exhaust of (1) air that is normally clean, but has the potential of becoming contaminated in the event of an operational upset (e.g., exhaust from a Secondary Confinement operating area) or during service operations when the zone is opened to a zone of higher contamination (e.g., a hot cell service area) and (2) air from a potentially mildly contaminated space (e.g., a Secondary Confinement area).
2. Moisture or corrosives in the exhaust that are capable of damaging or unduly loading the HEPA filters (or other components such as adsorbers) must be removed or neutralized before they can reach components that could be affected.4.HEPA filters and adsorbers (where required) must be tested in place at a prescribed frequency in accordance with ASME Code AG-1, Section TA[30] and ASME N510.[34] HEPA filter stages must exhibit a decontamination factor (DF) of no less than 3333 (99.97 percent efficiency), as determined by an in-place test performed in accordance with ASME Code AG-1.[30] DFs greater than 3333, which are required by some facilities, can be accomplished with multiple filter banks.

Table 2.10 Recommended Confinement System Differential Pressure (in.wg)[45]

Type of Facility	Primary/ Secondary	Secondary/Tertiary	Tertiary/Atmosphere
New	-0.7 to -1.0[b,c]	-0.1 to -0.15	-0.1 to -0.15
Existing[a]	-0.3 to -1.0[c,d]	-0.03 to -0.15	-0.01 to -0.15

[a]These guidelines should be used if the existing area/ facility differential pressure design basis is unknown or if there are no site-specific standards.
[b]Canyons, cells: -1.0 in.wg (minimum).
[c]Gloveboxes (air) typically operate at –0.7 to –1.0 in.wg. Gloveboxes (air) typically have alarms set at –0.5 in.wg. Gloveboxes (inert gas): -0.7 to –1.5 in.wg.
[d]Canyons, cells: approximately –1.0 in.wg.

NOTES:

1. It may be necessary in some cases to split a single zone into two areas, “a” and “b”, where one area contains a greater hazard than the other. If area “a” were the more hazardous area, it would be at a negative pressure compared with area “b”. Usually, no differential pressure guidelines exist for areas within the same zone. Therefore, maintaining proper airflow directions is typically the primary requirement.
2. Pressure cascades may need to be established within the secondary confinement. A 0.05–in.wg pressure differential between cascade stages is generally adequate.
3. If glovebox relief valves are included, they are typically set at –0.4 in.wg. Relief valves are designed for breach of the glove port.